THE UNIVERSITY OF CHICAGO

Round Table

PAST CLIMATES OF THE EARTH

An NBC Radio Discussion by

CESARE EMILIANI, RICHARD FOSTER FLINT

and HAROLD C. UREY

Including

CLIMATE AND CIVILIZATION

By PAUL B. SEARS

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HAROLD C. UREY, distinguished service professor of chemistry in the Department of Chemistry and in the Institute for Nuclear Studies, University of Chicago; winner of the Nobel Prize in chemistry, 1934; member of the chemistry division of the World War II atomic-bomb project at the University of Chicago

CLIMATE AND CIVILIZATION. *By* PAUL B. SEARS 11

THE UNIVERSITY OF CHICAGO ROUND TABLE
EDWARD F. ROSENHEIM, JR., *Director*

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Past Climates of the Earth

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MR. UREY: We are talking today about a problem which can be seen as one of history—history in the enormous geological perspective. We are speaking about the life of the earth and its climate. Joining me today in this ROUND TABLE are Dr. Richard Foster Flint, professor of geology at Yale University, who has specialized upon the continental features of glaciation in recent times, and Dr. Cesare Emiliani, research associate of the Institute for Nuclear Studies at the University of Chicago, who has been working in recent years upon temperatures as found in the ocean of the past. We are talking, as I said a moment ago, about a long period of time.

Flint, how long?

MR. FLINT: By radioactive dating four or five billion years, give or take a few million.

MR. UREY: During this long history there have been constant changes in climate. During the last fifty years we have evidence that the temperature of the earth has been rising; and we can expect that over this long history of the earth there have been small fluctuations of this kind throughout the whole length of time. In the long range there have been more important temperature variations.

Emiliani, how about those?

MR. EMILIANI: We know there have been at least eight major glacial times during which a vast portion of the earth was covered with ice. Each lasted several million years, and they were separated by intervals of great length, some two hundred and fifty million years of much warmer climate. The earth was at these times covered with widespread seas and had a much better climate.

MR. UREY: Of course, what we know best about this subject is really limited to rather recent times, because the records are so much better than they are for the very ancient times that Emiliani is talking about.

Will you tell us, Flint, something about the characteristics of these glaciations in recent times?

MR. FLINT: I suppose what you mean by "recent times" in this connection consists of the last million years or so of geologic history; and this is the time that most people think of as the Ice Age. In that, we had four different glaciations, each one maybe fifty to a hundred thousand years in extent, and they were separated from each other by probably longer periods during which the climate was more nearly like what it is at present. During the glacial times the high-latitude regions were pretty cold. We had cool, cloudy summers; we had very cold winters; we had lots of snow; and the northern half of Europe and the northern half of North America were covered with glacial ice.

MR. UREY: What are the signs by which we know of the ice ages? What are their characteristics?

MR. FLINT: You mean the geologic evidence of them?

MR. UREY: Yes, the extent of them and things of this sort.

MR. FLINT: The glaciers in Europe and America blanked out from habitation a good deal of the terrain in those regions, so that something like six million square miles of North America were covered with glacier ice, some of it as much as ten thousand feet thick, we think although we cannot measure it directly. This ice formed in the far north of each of the continents and rolled forward at a rate which we can approximate. It may have amounted to as much as a mile per year at times.

MR. UREY: A mile a year. That, of course, strikes me as being rather slow; but still, at the same time, if one thinks of the length of time that these ice ages occupied the North American continent, they would travel a very considerable distance.

MR. FLINT: To a geologist a mile a year is a high speed, a fairly high velocity.

MR. EMILIANI: In the lower latitude, of course, we had no ice; but we had much water—much more water than we have today—and great lakes which now are dry were filled with a great amount of water. Also, all these waters which filled up these lakes and went to form the ice in the higher latitudes, as Flint has said, came from the sea ultimately—and the sea level was lowered to a large extent, at least perhaps in the order of fifty to a hundred meters, or about three

hundred feet. This lowering of sea level is evidenced by drowned beaches—beaches which are much below the present level.

MR. UREY: Confining ourselves to the glaciations which have occurred in the last million years, let us consider what we have found out about them and let us ask, to begin with, the methods by which we have found out about these glaciations that occurred so long ago. First of all, of course, the older methods are mostly geological in kind, and, Flint, suppose you give us a little discussion of those.

MR. FLINT: We find over something like 30 per cent or more of the land area of the world a whole array of features which are quite similar to the features that we can see by looking around the edges of a glacier today. We find that the surface of the bedrock is scratched and grooved and polished in the way that only a glacier can do. We find boulders and stones of very distant origin lying scattered over the surface and imbedded in the surface soil, so that in the middle part of the United States, for example, we find boulders which have come from the central point of Canada and which have traveled seven or eight hundred miles to reach their present positions. We find in these regions hills that have been smoothed and molded so that they have taken on a streamlined form. We see similar hills emerging from melting glaciers today, and we can infer, quite closely, that this molding was done by the glacier ice itself. So, when we take all this evidence together, it makes an impressive case for very widespread glaciation.

MR. UREY: I remember last Sunday, while flying to Kentucky, that I could see just about how far south the glaciers had gone from the character of the terrain below me. About a little bit south of Indianapolis the terrain changed from a nice, smooth glaciated region to a rugged, hummocky one, the sort of thing that one sees in southern Indiana and Kentucky and southern Illinois; and this boundary I understand goes all through the Middle West in this way.

MR. FLINT: We could say that it comes onto the continent from the Atlantic Ocean just about at New York City and crosses New Jersey and Pennsylvania, passes through about the site of Cincinnati, just about through St. Louis, and very close to Kansas City, to give you an idea of the extent of it.

MR. UREY: How far west does it extend?

MR. FLINT: It trends northwest from the vicinity of Kansas City, so that it goes up through the Dakotas and then swings around westward in Montana and finally crosses into Canada up near Glacier Park.

MR. UREY: And continues, as I understand, on the east side of the mountains clear up, so that even Alaska was not glaciated particularly. Was the north part of Alaska glaciated?

MR. FLINT: The mountain regions of Alaska were glaciated, but the low country was not.

MR. UREY: That is interesting. Of course, another method that has come in, in recent times, for learning something about this problem is the radiocarbon dating method, which was developed here at Chicago by Dr. Willard F. Libby. Before we go on to other things I would just like to mention how this is used. Carbon 14 is constantly being produced in the high atmosphere by cosmic rays, and the radioactive carbon, once produced, slowly decays with time. If the carbon, however, of the atmosphere becomes buried in the ground in the form of wood, or anything of that sort, it no longer receives an additional supply of radiocarbon from the action of cosmic rays, and so the radiocarbon slowly decays with time into nitrogen. What one needs to investigate is the amount of carbon remaining at any time. Knowing the rate with which this occurs, it has been possible to set up a radiocarbon dating method. This is applicable to determining dates that extend back over a few tens of thousands of years, not much longer than that; and so it covers very much the time of the last glaciation. This has proved to be an exceedingly valuable method for investigating, one of somewhat the newer type. Of course, there has been a development of methods of measuring temperatures.

Emiliani, you have been working on this—suppose you tell us about it.

MR. EMILIANI: First of all, I wish to say that this method was developed several years ago at this University by Dr. Urey and his coworkers; and it involves the differential concentration of oxygen isotopes in the calcium carbonate of marine organisms. There are two oxygen isotopes which are the most abundant; these are oxygen 16 and oxygen 18. Depending upon the temperature, various pro-

portions of these two isotopes will go into the calcium carbonate. This record is preserved as long as the shell material is preserved, and therefore is not subject to the time limitation of carbon 14 dating, but fossils as old as can be found in a preserved condition may be used.

MR. UREY: We have discussed some of the methods for securing information of this kind, and I think it would be well, and perhaps most interesting, to review something about what has been secured as a result of studies of this kind. Of course I think the most dramatic thing for most of us is this enormous advance of ice that occurred in relatively recent times right down over the spot where we are sitting, and where a great many people in the Middle West live.

I would like to suggest, Flint, that you tell us something about this advance that we have learned by these methods.

MR. FLINT: I am glad to do that, because the radiocarbon results that we have on the last activities of the ice sheet in this region excite me very much. We have a whole series of dates on samples—most of them consisting of pieces of wood that are imbedded in the layer of earth and stones spread out over the northern part of the United States by the glacier during its advance. We have so many of these from so many localities, all of them telling the same story, that we feel fairly confident that we have a good picture now of the sequence of events. We can say, I think, that without any doubt the last really big glacial push from Canada into the United States took place between twenty-five and thirty thousand years ago. This wood consists of pieces of forest trees that are spruces and firs, forming the sort of forest that you now can see north of the Great Lakes region, up in Canada. Evidently the ice, in pushing south through the Great Lakes region, simply bulldozed these forests in a wholesale manner and broke up the trees and incorporated them into the trash which it was carrying forward.

We have a number of these dates which give us a sort of clock, indicating the times during which successive forests were bulldozed; in consequence we can say that this big glacial push reached its maximum extent down somewhere south through Columbus, Ohio, and down through central Indiana and Illinois just about eighteen thousand years ago; and then it began a sort of wavering retreat, until it had cleared the whole of the Great Lakes region. We know that because

there is evidence that the Greak Lakes at that time were full of water. That happened about twelve thousand years ago. Then, once more, there was a push; but this was a feeble effort, and another forest or two was bulldozed. This time the ice only managed to get down as far as Milwaukee, and then it gave up the ghost and has been engaged in a sort of a wavering melting ever since. Today the last bits of it are up in northern Canada, in Greenland, and in Iceland.

MR. UREY: This Greenland ice is, of course, a true glacier?

MR. FLINT: Oh, yes.

MR. UREY: Exactly of a similar kind to what extended over this region?

MR. FLINT: Yes. I think that by taking a good look at the Greenland ice sheet we could get a good picture of what Illinois, Indiana, or Ohio looked like, say, eighteen to twenty-five thousand years ago.

MR. UREY: Looked awfully cold, I should say.

MR. FLINT: Looked awfully cold; and there must have been some pretty strong wind.

MR. EMILIANI: Temperature variations, therefore, were indicated by all this geological evidence in the high latitude, but now we have found that there were important temperature variations in the tropics, that is, at much lower latitude. The evidence which we have found was obtained by measuring with the isotopic method the temperature registered by pelagic Foraminifera.

MR. UREY: Do you mean by "pelagic" these floating organisms?

MR. EMILIANI: Yes. These are small microscopic organisms which float near the surface of the sea and deposit a calcium carbonate shell. When the animal dies—it lives usually a few weeks—the shell falls to the bottom and accumulates there. Some of these animals, also, do live at the bottom, but we have used for this particular study those which live at the surface. Now, in order to obtain a sample of the bottom sediments, corers are used. These are tubes maybe sixty or seventy feet long, with heavy weights of lead, which are lowered to the bottom of the sea, and are stuck in the sediment. Then they are raised filled with these sediments; and the column may be as long as sixty feet. Of course, the deeper the layer is below the surface of the

bottom sediments, the older it is. We may reach back in time some two million years. Now, in this column of sediment, which is inside the tube, there are alternating accumulations of colder and warmer types of shells, which can be seen by just looking at the various species. Also, we can separate these shells, treat them chemically, and make an isotopic analysis. This way we find that during the last few hundred thousand years in these lower latitudes there have been variations of temperature somewhere between, say, 29° C. and 22° C. These were rather periodical. The evidence of this seems to be fairly good and of the order of magnitude of between forty thousand and maybe fifty or sixty thousand years, as determined by extrapolating the carbon 14 dates made on this material by Dr. Hans Suess in Washington.

MR. UREY: Of course, the times that we are talking about here are comparatively short, some hundreds of thousands of years. But I think it might be interesting to go back even longer periods of time and notice what changes in temperature seem to be indicated. This method of measuring temperatures enables us to go back, we think, about a hundred and twenty-five million years to a period that was called the Jurassic. I may say this work was done mostly by Dr. Heinz Lowenstam and Dr. Samuel Epstein, some years ago. Here we find that an organism from the northern part of Scotland recorded a temperature of about 25° C. That is about the temperature of the Caribbean at the present time. It was a rather interesting specimen, very similar to the modern squid. Also, somewhat later than that, sixty million years ago, we found that the temperatures in the neighborhood of England, again, and Europe, and the southern part of the United States were much alike; and this time the temperature was somewhat lower, about 18° C.

I might say, for comparison, that the neighborhood of England, at the present time, is 10° C. or 11° C. on the average. And thus it appears that, back a long period ago, the temperatures of the earth were considerably higher than they are now. And I think this is the sort of thing that geologists have felt was characteristic of the earth at that time, from other evidence—from the animals that lived and from the distribution of plants and things of this sort. It is interesting, indeed, that we developed these new physical methods and find at

the end the only thing we have done is to confirm the work that has been done by older methods previously. Still, it adds a little bit of perhaps exactness to this previous knowledge, and I think recent work, Emiliani, shows that even since then there have been some changes.

MR. EMILIANI: As you said, there was warm temperature, apparently a temperature maximum, some hundred and fifty million years ago; and then the temperature was somewhat cooler some seventy million years ago. Now, I have been analyzing these small microorganisms which live in the sea; but this time, instead of using those that live at the surface, I used those that live at the bottom. They were collected by the Swedish Deep Sea Expedition of 1947–48 at the bottom of the Pacific Ocean at a depth of about twelve thousand feet; and they are about thirty million years old, about eighteen million years old, and about two million years old. That is, there are three groups of different ages. Now, the three groups of different ages give a temperature of about 10° C., about 7° C., and about 2° C., showing a steady decrease of the temperature from about thirty million years ago down to about two million years ago or one million years ago. These temperatures are the temperatures of the bottom water of the Pacific Ocean, very deep sea levels, and therefore they also correspond to a general decrease of the temperature throughout the earth.

MR. FLINT: We also have evidence of temperature changes going back of any of these times that you have mentioned.

MR. UREY: Oh, yes.

MR. FLINT: In the Permian period, which was around two hundred million years ago, or perhaps a little more, there is evidence on several continents of quite widespread glaciation rather similar to this thing we have been describing from within the last million years. Curiously enough, it seems to have affected the Southern Hemisphere more than the Northern. We do not know why that is, but there is no doubt that there was a lot of ice on the surface of the earth at that time, and, therefore, the temperatures of the lands must have been rather low perhaps over a period of some millions of years.

MR. UREY: If we piece together this information, I would describe

it somewhat as follows: Two hundred and fifty million years ago there was a glacial period, temperatures similar to those that we find on the earth now, or characteristic of the last million years, or something of that sort; and then about one hundred and twenty-five million years ago it appears that at least the region of England was relatively warm. Somewhat later, sixty million years ago, the temperature seems to be a little bit lower. Then we cannot quite match together what Emiliani tells us about the bottom of the Pacific Ocean and what happened in Scotland; but surely it is true that in the last thirty million years the temperature has been steadily going down, until now we are back to where we were in the Permian period, at a relatively low temperature, so low that we get ice upon the earth again in large quantities.

It looks as though we had a steady rise for a time to a mild climate, when the dinosaurs lived, and there were low, shallow seas on the earth, and then a steady decline, with no signs of its stopping, as a matter of fact. It is a little bit disturbing to think of that. But at least the temperature has arrived at the present time at rather low values. Of course, we might reasonably ask what effect this has had upon man?

Flint, you have been much interested in this.

MR. FLINT: It certainly has had an effect on life of all kinds. The various kinds of animals were forced to decamp as the ice sheets rolled forward. We have arctic animals, like musk oxen, all the way south to Arkansas; and we have reindeer down in southern France that were obviously pushed into those positions by the oncoming ice; and man, too, who was much more able to get out of the way. Depending on how you define man, you can say that man has been around here for a long time; that our own species seems to have successfully survived the last two big glaciations. He has been here certainly during half of the last million years and seems to have ingeniously survived without much difficulty.

MR. EMILIANI: That is nice to know, because it is possible that we will have another ice age, or a number of more ice ages or glaciations, in the future, some tens of thousands of years from now.

MR. UREY: Yes. Let us see, we would say that probably the ice age of the Permian lasted a few million years.

MR. FLINT: I think that is reasonable.

MR. UREY: And the present ice age has lasted perhaps a million years. We would think that perhaps we might be right in the middle of this ice age. That is, we see four different periods at which the ice advanced.

MR. EMILIANI: During the last million years.

MR. UREY: During the last million years. This process of another advance of the ice, and another interglacial, and then another advance of the ice would seem to be something that we might expect to happen in the future. As a matter of fact, if man has survived in the past, it looks to us very much as though he may survive in the future. I mean that he may survive the ice ages in a quite satisfactory way; perhaps he will not survive the Atomic Age. There are indications that he may be inconvenienced seriously by the advance of ice in the future, be pushed down into Africa and South America. But at least it does not look as though the species will be killed off by this particular development.

CLIMATE AND CIVILIZATION[1]

By PAUL B. SEARS

*

The most cursory knowledge of such traits as the use of fire, clothing, shelter, and diet makes it clear that climate is an implicit function of the process we call culture. Since civilization can be defined as an advanced manifestation of culture, it seems reasonable to infer that the relation persists at the advanced level. The issue is clouded, however, because the techniques of civilization seem at times to have emancipated it from the controls that operate under more primitive conditions.

So far as the genesis of civilization is concerned, we do not have to rely solely upon inference. Civilization did not begin until men had surcease from the endless quest for nourishment. Such respite can come only from an efficient agriculture. The classic cradles of that art are also those of civilization—the now semiarid Middle East with its wheat, Latin America with maize, India and Indo-China with rice are examples. In none of these areas was temperature unfavorable to human comfort or to the growth of crops. In all of them adequate moisture was available, directly by rainfall or through drainage from higher lands.

This is not to say that climate alone was involved. But in each instance it has been an indispensable element in a matrix that included favorable conditions of topography, mineral nutrients, and the indigenous fauna and flora. None of these is really independent of climate. Even in the sophisticated food production of today these factors continue to operate, and the existence of an optimum climate for staple crops is a major economic fact. The problem is not whether climate is involved, but the manner and degree of its involvement.

We encounter a difficulty at the outset. Even the best of our present climatic classifications are somewhat arbitrary, provisional, and empirical. Aside from the technical difficulties of the standardizing of observations over long periods of time, it is possible to subdivide climates to almost any degree of refinement—for example, to conditions

[1] Reprinted, with permission, from Harlow Shapley (ed.), *Climatic Change* (Cambridge: Harvard University Press, 1953), pp. 35–49. Because of limitations of space, Figures 1–4 and the bibliographical references of the original have been omitted.

on opposite sides of a house, or to the interior and exterior of a hedge. Little is on record about one of the most important factors of climate, that is, evaporation, which has had to be treated as a derivative from other, measured factors. In consequence, the reliability of existing classifications can be tested only by comparing them with such geographical phenomena as natural vegetation and soils, which are regarded as an integral expression of climate. It is with these reservations in mind, then, that the following discussion is presented.

So far as I know, no single species of plant or animal can transgress very far beyond its characteristic climatic range, unless it undergoes evolutionary changes that in turn set new limits. For this phenomenon there are good and sufficient reasons to be found in physiology, which finds for each species its range of tolerance in respect not only to the several factors of climate but to their combinations and rhythmic patterns.

The striking exception is man, with a relatively small group of organisms that accompany him and thrive, so to speak, in the shadow of his presence. This does not mean that man lacks physiological limits. Rather he enjoys the benefits of that vicarious and cumulative experience which we call culture, and by means of it can adjust himself, often with great advantage, to almost any type of climate the earth provides. By cultural traits such as clothing, shelter, irrigation, diet, and regimen, man, without evolutionary physical changes, has broken through what must have been his original climatic limits.

That such limits once existed seems reasonable enough, despite the scanty fossil evidence. It is true that man's range during the prehuman stage may have been fairly extensive, for the geological climate in general was milder than it became after the human adventure began. If man became man during the late Pliocene period or early Pleistocene, the human stage appears to have begun in an environment in which species ranges were shrinking, owing to expansion of polar climates.

For simplicity of discussion, and for other reasons, I shall assume that we are still in the Pleistocene, which I shall equate with the Human period. On that basis, the development of human culture has occurred in the face not only of strongly marked climatic zones but of strongly marked climatic pulsations, accompanying repeated advances and retreats of continental ice. Some of these events are con-

veniently summarized in our long pollen records from Mexico and New Mexico, which show at least three intervals during which climate has been as warm and dry as it is now.

Thus man, in the early stages of his culture, was doubtless obliged to move at times, and at other times he had excellent opportunities to do so. Presumably he made appropriate cultural adjustments under both conditions.

The real questions as to the relation of climate to civilization are two, as I see them. First, to what extent does climate set limits to the process of civilization? Second, to what extent is the *quality* of civilization an expression of climatic influence? The first of these questions has been a challenge to technology, the second a source of lively controversy.

Of the approximately fourteen acres per capita of land surface available to the present world population, nine are reckoned as either too dry, too cold, or too rough to be productive. Of the remaining five, slightly more than three, for a variety of reasons, are substandard for the production of food. This leaves only a little more than one acre of land per capita to carry the burden of feeding the world's population. The bulk of good land lies in those areas of the temperate zones where the balance between rainfall and evaporation is such as to give optimum mineral nutrient cycles for high protein production. Speaking generally, here are the grain belts of the world. Probably these regions must continue to bear a large share in the feeding of the world. They also contain the soils most responsive to further improvement. In other words, each increment of capital investment in these regions will yield the highest return.

Another interesting possibility has been suggested by Firman Bear, who maintains that to keep such soils from deteriorating, they must be held at the highest level of production. The responsibility of those who control these lands, for the continuing support not only of their own civilizations, but of civilization everywhere, is in any event impressive.

In the present state of technology, civilization is no longer limited to those areas that can underwrite the adventure in terms of their own food production. The tentacles, or if you prefer, the benevolent hands of civilization now stretch past the most formidable climatic barriers into outposts where mineral wealth, military considerations, scientific curiosity, or the mere sense of adventure may justify the effort. But the

metabolic centers of civilization remain where there is control of nutrient sources sufficient to provide energy for more than bare subsistence. And the location of those centers is certainly an expression of climate. It is in this sense that we answer our first question—the extent to which climate sets limits to the process of civilization.

This brings us to the intriguing and controversial problem of the relation of climate to the quality of civilization. By the book (for it is necessary now to see what assumptions are involved), civilization has been defined as "an advanced state of human society, in which a high level of art, science, religion, and government has been reached." Philosophy is not included in this particular definition; nor is there any mention of the joy of living, which certainly is not a negligible consideration. Of the four elements listed, only one, science, can be measured with some degree of objectivity. Even science is not immune to the charge of prejudiced judgment, as certain recent events show. These events include not only the attacks on Morganism in genetics, but also the resolutions condemning, on the basis of the world-view of dialectical materialism, the "sterile, idealistic" theory of Linus Pauling of resonance in organic reactions. There are also the accounts by elderly colleagues of their experiences when visiting continental European laboratories and attending international scientific congresses a generation or more ago, which indicated that chauvinism in science is not exactly new.

> For each, with profound satisfaction
> Which our speeches and writings attest,
> Beholds other cultures in action
> And pronounces his culture the best.

Yet I doubt that the problem is quite as hopeless as it sounds; for there are plenty of competent people, willing to lay aside prejudice and preconception to the best of their ability and consider the evidence. The difficulty of consensus as to the rating of civilizations in terms of quality is less among such individuals than is the technical obstacle, now becoming clear as a result of recent advances in cultural anthropology. Simply stated, each culture (hence each civilization) possesses its own internal logic, which must be evaluated from the inside, so to speak. It is only after a sympathetic participation in more than one culture that any fair comparison can be drawn.

The physical limitations of this method are obvious. Meanwhile, any respectable comparison must be confined to those aspects of civilization that have been established as a kind of international currency. This procedure, I suppose, was the intention of the late Ellsworth Huntington, who attempted his own rating of civilizations. His check list is as follows:

Power of initiative,
Inventiveness and capacity for formulating new ideas,
Ability to develop philosophical systems,
Ability to carry out far-reaching enterprises covering long periods and areas,
Power to lead and control other races,
Highly developed system of education,
Application of principles of hygiene,
Standard of honesty and morality,
Degree of personal safety,
Sense for beauty in art (architecture included),
Sense for beauty in literature (belles-lettres),
Sense for beauty in nature (scenery, flowers, etc.).

Whatever reservations we have as to his method, I am inclined to accept the notion that the capacity for sustained, creative (as opposed to destructive) energy lies close to the heart of the problem. A high level of nutrition is, of course, involved in supplying energy, but gives no guarantee that it will be creative. The followers of Malan in South Africa appear to be well nourished. The problem is one of values and direction, and I am unable to see where climate has much bearing on either, with this possible exception: if climate is such as to create a steady supply of problems that must be solved while holding also the promise of rich returns for maintenance of a satisfactory social system, then climate may influence both values and direction of effort.

Huntington's thesis, however, is more physiological than this. He saw in the cool temperate regions, with their frequent cyclonic disturbances, a kind of perpetual system of stimuli to high creative effort. But something more than stimulus is needed. The physiological aspects, apart from nutrition, deserve to be thoroughly explored. We have studies on the combined effects of temperature and humidity on productivity, and numerous others on illumination, fatigue, rhythm, and morale. There is also a growing volume of research on human de-

velopment, on human relations, and on the cultural process itself, all of which bear upon our problem.

The thermal economy of the animal body, certainly an important factor, has its analogy in the internal-combustion engine. Heat is an inevitable concomitant of the oxidation of food, as of fuel, in accomplishing work. Whatever heat is not required to maintain the system and supply the energy for work must be disposed of through radiation. This idea has been advanced by Brody and others in breeding livestock for warm climates. Varieties like the Brahma cattle, which present the largest radiating surface through bodily contour and skin folds, are considered the best.

Mills also has studied the radiating surfaces of various animals—the ears of rabbits and the tails of rats, for example—and lays great stress on the heat economy of the human body as a factor in achievement. He is inclined to write off the cold and hot climates as assets for civilization. In the former too much energy must be used in maintaining a working temperature, in the latter necessary radiation is too much of a burden.

Conceding that we may have to regard the colder portions of the planet as outposts of its core civilizations, we come to the question of the tropics. Although the tropical rain forest is a tremendous producer of organic material, it is a meager source of human subsistence. Equally serious is the problem of the human thermal budget in the tropics. Neither problem is entirely hopeless, provided we do not expect the people of the tropics to lift themselves by the straps of their own sandals. They must utilize a great deal of the knowledge and skill developed in existing civilized centers as a nucleus on which to build. I agree wholeheartedly with Bates that mere transplantation is not enough; there must be developed within the tropics an endemic culture, based primarily on a new body of scientific research.

One more point remains to be discussed—the challenging notion of Huntington that climatic change has been a major factor in the geography of civilizations.

Whatever one's judgment of various past civilizations may be, there is no question that the centers of civilization have shifted with the passing of time, with respect not only to political power, but to general creative activity. And the direction of movement has generally been away from the tropics, although the decline of Icelandic great-

ness and the abandonment of Greenland are exceptions. Many of the remains of former glory certainly lie in areas that are now inhospitable desert, or, like Ankgor and the Mayan cities, humid tropical woodlands.

Huntington suggested that climatic change has been a paramount factor in the destiny of these ancient lands, and to support that idea he advanced many interesting arguments. Certainly there have been changes, and they have affected human activity. There is abundant evidence, not only from fossil shore features, but from sediments of once deep lakes in many now dry basins in our own Southwest and Mexico. It is now known that the retreat of continental ice from its extreme position has been a vacillating process, marked by several advances and retreats—a process not yet stabilized. Several lines of evidence indicate that the past two centuries have been marked by rising temperature.

The number, intensity, and duration of these late-glacial phases is still under study, and so is their exact chronology. Yet even when these problems are much better understood than they now are, immense difficulties will remain in the way of knowing to what extent and in what ways climatic change has been involved in the rise and fall of civilizations. In fact the life history of civilizations, apart from possible environmental influences, is still a knotty problem for scholars, who are likely to offer explanations as numerous as their various backgrounds. Did Rome fall because of moral corruption, economic weakness, geographic determinism, or a kind of inevitable senescence through which all civilizations must pass? Did she ever fall? Or has she expanded her culture throughout the world, with accretions from many sources and under new political forms?

The civilization of Babylon, as far as economy is concerned, apart from its efflorescence in empire and the arts, endured for a much longer period than the time that has elapsed since the final destruction of its irrigation system by the Mongols. But some of the events preceding that destruction should be noted. For centuries the operation of agriculture had been increasingly burdened by heavy loads of silt in the life-giving canals. So much labor was required for their annual cleaning that little leisure remained for anything else, and the long piles of silt beside the canals grew steadily in height and volume. Presumably this was due to increasing pressure, through cutting and grazing, upon the vegetation of the highlands whose run-off sup-

plied the water. Under those conditions, the landscape became increasingly vulnerable to the effects of climate with its infrequent but violent rains and dry-season winds.

In all of the great Mediterranean civilizations, even Egypt, similar symptoms of environmental disintegration are found, with economic decline and a decrease in creative activity that we may concede without any question as to what constitutes civilization. That there has been no decline of innate capacity in the people themselves is suggested by the recent achievements of native leaders, trained at Beirut and abroad. But everywhere the primary evidence is that of human pressure on a vulnerable landscape, aided and abetted by that at once most useful and most noxious of animals, the goat.

It is a weakness of Huntington's argument that he did not reckon with man-accelerated erosion and other cultural influences. In the judgment of the late Dr. Jacob Lipman, eminent student of soils, the erosion in Palestine far exceeded in its disastrous effects any real or supposed changes of climate since the days of milk and honey. This view is supported by the observations of Lowdermilk, and by those of the late Dr. F. W. Oliver, who retired to Egypt and spent his final years in the study of wind erosion and the process of desertization. I had occasional letters from him during this time, which, with his published papers, showed clearly the power of vegetation to stabilize environment, even in that dry region, and the disastrous effects of human pressure.

There is, in fact, early contemporary evidence to the same effect in a striking quotation from Plato, recently unearthed. It might have become well known earlier if his readers had not been preoccupied with linguistics and metaphysics. Critias, speaking of the ancient kingdom of Attica, states: "What are now her mountains were lofty, soil-clad hills; her so-called shingle-plains of the present day were full of rich soil; and her mountains were heavily afforested—a fact of which there are still visible traces. There are mountains in Attica which can now keep nothing but bees, but which were clothed, not so very long ago, with fine trees producing timber suitable for roofing the largest buildings; and roofs hewn from the timber are still in existence. There were also many lofty cultivated trees, while the country produced boundless pasture for cattle. The annual supply of rainfall was not lost, as it is at present, through being allowed to flow over the denuded surface

into the sea, but was received by the country, in all its abundance, into her bosom, where she stored it in her impervious potter's earth and so was able to discharge the drainage of the heights into the hollows in the form of springs and rivers with an abundant volume and a wide territorial distribution. The shrines that survive to the present day on the sites of extinct water supplies are evidence for the correctness of my present hypothesis."

Equally convincing is the testimony of that remarkable engineer Henrico Martinez, who wrote less than ninety years after the Spanish Conquest of Mexico of the increasing downwash of mud and the stripping of soil from the uplands due to cutting of the forests and the unrestricted grazing of Christian cattle.

If I seem to have made a bad case for the influences of climatic change, I have done so only to clear the air. I must confess that the idea has always intrigued me, even though the years have brought an increasing appreciation of the difficulty of the problem. After it had been fairly well established that a period of post-Wisconsin climate warmer and drier than the present might explain the numerous prairie relicts in forested Ohio, and that such a climate had existed, as shown by pollen analysis, I ventured to apply this information to a curious problem in Indian cultural migration.

A map that shows the prairie relicts of the upper Mississippi Basin outlines also the archeological remains of the group of cultures known as Mound Builders, which exhibit definite southwestern affinities. By the time of the first European settlement, these cultures had been replaced by types which, while maize growers also, were essentially forest dwellers. The evidence for this development led me to suggest that the flowering of the Mound culture had been encouraged by a northeastward shift in the maize optimum. Lest this idea seem far fetched, let it be remembered that our modern economy is deeply affected not so much by the limits in which a given crop can possibly be grown as by the area of its optimum climate. What applies now should have applied a fortiori to a simpler technology.

It was with considerable comfort that I learned later of good evidence in Europe that Neolithic culture had moved northwestward into the Baltic area by virtue of just such a warm-dry climate as that postulated for the advance of the Mound Builders. Moreover, recent carbon 14 datings place much of the activity of the latter group in the period of

desiccation that marked the end of the Late Archaic in Mexico and the establishment of the Teotihuacan culture (500 B.C.–A.D. 800). That the Mound culture continued on for a time during the ensuing moister period serves to confirm the reasonableness of the general idea. It is certainly not to be expected that such a solid development would crumble at once.

The influence of even brief climatic fluctuations, where climate is a limiting factor, is no longer in dispute. Migration in our own Great Plains has shown that a drouth of only a few years' duration can profoundly affect segments of our own culture, despite our technological resources.

The Bat Cave discoveries, on the shores of a dead and desert lake bed in western New Mexico, exhibit the stark operation of climatic factors. Here the Indians grew maize for some thousands of years before they abandoned the site. When a lake dries up, those dependent upon it for their economy have only one direction to go—that is up. The not-too-distant uplands abound in archeological sites, where either springs or brooks occur, but all such sites contain artifacts of more recent date than those of the Bat Cave site. Incidentally, the sediments of this ancient lake contain much pollen, and even the shallow borings we have made to date reveal climatic fluctuations of considerable magnitude, and present consistent evidence as yet unpublished, of a present-day climatic trend toward warmth and desiccation.

It is in the Basin where Mexico City is located, however, that we have the most dramatic evidence of climate as a limiting factor. Here the Bat Cave theme is repeated on a grand scale, with variations. Our evidence of climatic change as indicated by the fossil-pollen profile is sustained not only by known lake levels but also by a thorough study of some 70 meters of sediment. Briefly, the Archaic culture, which flourished from about 2000 to 500 B.C., did so by virtue of an initial period of moist climate and high lake level. About 500 B.C., at a time of extreme desiccation and low lake level, the Late Archaic culture became early Teotihuacan. It then moved up to high ground at the northern end of the Basin—some 30 meters higher and 30 kilometers away—where, evidently, were sources of ground water, doubtless supplemented by trapped rainfall.

The end of the Teotihuacan culture was as sudden as the beginning

and took place during a moist period, about A.D. 800. Vaillant suggested that deterioration came because the protecting forests had been destroyed to make fuel for the extensive burning of lime. Cook later found evidences of extensive erosion during the Teotihuacan interval. It may be that the destructive effects of cultural activity were great enough to offset the blessings of returning moisture.

At any rate, the lakes presently filled up and a lacustrine culture returned to the Basin below, developing to full flower by the time of the Spanish invasion in 1521. Artificial drainage since that time has largely canceled the advantage of more favorable climate. Even this moister, more favorable climate was not permanent. During the summer of 1952 pollen profiles from Los Lagunas de Zempoala in the high-altitude conifer forest revealed the recent warm-dry trend, confirming similar evidence already in hand from New Mexico. We had been unable to secure adequate evidence from material collected in the Basin of Mexico, where there has been much recent disturbance, nor does it appear in the pioneer study by Deevey made at Lake Patzcuaro. It is safe to say that the drainage of the Basin of Mexico comes at a particularly bad time in the climatic sequence.

Deevey, in addition to showing the possibility of pollen analysis in Mexican lake sediments, and indicating its importance, found evidence of human activity in the form of a few grains of maize and agave pollen. Maize is not today known to survive without the aid of man, and geneticists agree that its pollen does not travel far from the source. In addition, the place and time of origin of maize have been the subject of much consideration.

No maize pollen was found in our ten archeological cores in the Basin. One station has since shown it, but some of the others were probably too far from the ancient corn gardens. However, in examining two deep cores obtained within the present City of Mexico, my associate, Mrs. Kathryn Clisby, found maize pollen to a maximum depth of 9 meters. This takes maize back at least 4000 years, to the Early Archaic. Within the past few months, on completing her analyses, she found grass pollen of unusual size, matched only by that of maize and its relatives teosinte and tripsacum, at the depth of 70 meters, or well back into the Pleistocene.

This material was submitted to Dr. Barghoorn and Miss Wolfe at Harvard, who, with Dr. Mangelsdorf, have given us generous col-

laboration. While the identity of the pollen cannot be confirmed without further rigorous study, the most likely possibility is that maize is represented. Evidence from sediments and pollen indicates deposition under conditions of climate similar to those accompanying the maize pollen at 9 meters and above. The long intermediate interval of 61 meters bears evidence of much activity, climatic, volcanic, and topographic.

Meanwhile the evidence for Pleistocene man in Mexico, while not established to general satisfaction, is strengthening. If there, did he know and use maize or a closely related grass? Did he carry either elsewhere and use it as a basis for civilization farther south during the ensuing interval? Or was the grass whose large pollen occurs at 70 meters a temporary intrusion from some other place of origin? These and other important questions may be solved only by the expensive and laborious process of deep drilling in the numerous extinct lake beds that occur from New Mexico through Central America and down into the Andean country, where the records now lie buried. But any prospect of clearing up the origin and movement of maize through a study of cores representing, say, the past 10,000 years now seems much less promising than we had supposed.

Thus have complications been added to one phase of the already difficult but endlessly intriguing problem of the relation of climate to human culture. The only hope lies not in isolated studies but in the fullest coöperation of many disciplines and laboratories. In this instance, we are indebted not only to generous Mexican colleagues but to the resources of Oberlin, Yale, Harvard, Ohio State, and the University of Massachusetts, with support from the Geological Society of America and the Wenner-Gren Foundation, and more recently, the National Science Foundation.

SUMMARY

Climate and civilization are both complex phenomena, whose analysis and evaluation present many technical difficulties. Their relation is complicated by the fact that man, through cultural processes, can transgress climatic boundaries such as limit the ranges of other species.

That climate affects civilization profoundly is not questioned. The relation, however, is not simple. Stimulus to activity and favorableness

for sustained effort have been suggested as keys. So has the moisture budget, but this last has often been more seriously affected by cultural practices than by climatic change. On the other hand, soils capable of high protein production are an expression of climate and are essential to sustained civilization.

Civilization (relatively speaking) has been affected by climatic changes that shift the areas of optimum production of basic food plants. This is established for Neolithic migration into the Baltic region at the time of the Thermal Maximum, and probably is true for advanced maize cultures in the Upper Mississippi drainage. Drying and renewal of lakes in the Basin of Mexico have caused important cultural shifts, as has the disappearance of lakes in the Southwest. Drouths of even a few years' duration have been factors in internal migration within the United States.

The problem can be dealt with only by coöperative research on a wide front—research that takes account of the many respects in which climate can affect civilization, of the cultural process itself, and of the often drastic effects of land use on the environment.

Because of the critical role played by maize in American civilizations, that plant serves to illustrate some of the complexities to be met. Its pollen has been recoverd to a depth of 9 meters in Mexican sediments that date back into Archaic cultural levels. But an apparently identical pollen is preserved at depths of 70–75 meters, certainly well back in the Pleistocene. Modern maize is dependent upon man, and the evidence for Pleistocene man in Mexico is increasing; nevertheless, the whole question now appears to be much more difficult than had been supposed.

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